SURVEY OF CONTAMINANTS IN WATERFOWL AND COLONIAL WATERBIRDS AT THE MICHIGAN ISLANDS NATIONAL WILDLIFE REFUGE

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FEBRUARY 1995

STUDY IDENTIFIER: 88-3-116

ENVIRONMENTAL CONTAMINANTS PROGRAM
DIVISION OF ECOLOGICAL SERVICES
EAST LANSING FIELD OFFICE
U.S. FISH AND WILDLIFE SERVICE

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Background

The Michigan Islands National Wildlife Refuge (NWR) consists of five islands located in northern Lakes Michigan and Huron. Gull, Pismire and Shoe Islands are situated within the Beaver Island group in northern Lake Michigan (Figure 1) and are administered by Seney NWR. Shoe and Pismire Islands are designated wilderness areas. Scarecrow and Thunder Bay Islands are located in the outer reaches of Thunder Bay, an embayment of northern Lake Huron (Figure 2). The Thunder Bay River, which drains a large watershed in the northeastern Lower Peninsula of Michigan, empties into the head of the bay at the city of Alpena, Michigan. Scarecrow Island is a designated wilderness area. Both islands are administered by Shiawassee NWR.

The history of these islands is similar to other islands within the Great Lakes in terms of the impacts of industrial contamination on fish and wildlife. Although well removed from the traditional end-of-pipe point sources of pollution, these islands experienced similar reproductive impairments to colonial waterbirds and waterfowl that was characteristic throughout the Great Lakes in the 1960s and 1970s. Reproductive impairment in these species was largely attributed to DDT and metabolites, PCBs and other organic compounds manufactured and discharged post-World War II. Following the banning and/or control of many of these industrial and agricultural contaminants, reproduction in many of the avian species began improving throughout most of the lakes in the early 1970s. Although the islands within the refuge are located in what is considered "cleaner" areas of the Great Lakes, there is little recent data on the magnitude of current contaminant exposure in avian species. This study was designed to fill this data gap, through the collection and residue analyses of eggs and tissues from the common breeding species on the islands.

Methods

A survey of eggs and tissues from colonial waterbirds and waterfowl was conducted during the 1988 field season. The study design called for the collection of 12 eggs from each species and colony. A total of 109 fresh and 3 addled eggs were collected from nests on the refuge islands or nearby islands between May 11 and July 4, 1988. The eggs were transported on ice to the East Lansing Field Office (ELFO) and refrigerated prior to individual archiving into chemically clean jars. All encountered embryos were aged and examined for deformities. Colonial waterbird eggs were individually homogenized by the Patuxent Analytical Control Facility (PACF). Equal sized aliquots were taken from each egg and combined to form a single composite sample for each breeding colony. This resulted in 10 fresh egg composites from 5 island colonies for the black-crowned night heron (*Nycticorax nycticorax*), great blue heron (*Ardea herodias*), double-crested cormorant (*Phalacrocorax auritus*), ring-billed gull (*Larus delawarensis*), herring gull (*L. argentatus*) and common tern (*Sterna hirunda*). Eggs from the red-breasted merganser (*Mergus serrator*) and Canada goose (*Branta canadensis*) remained as individual samples.

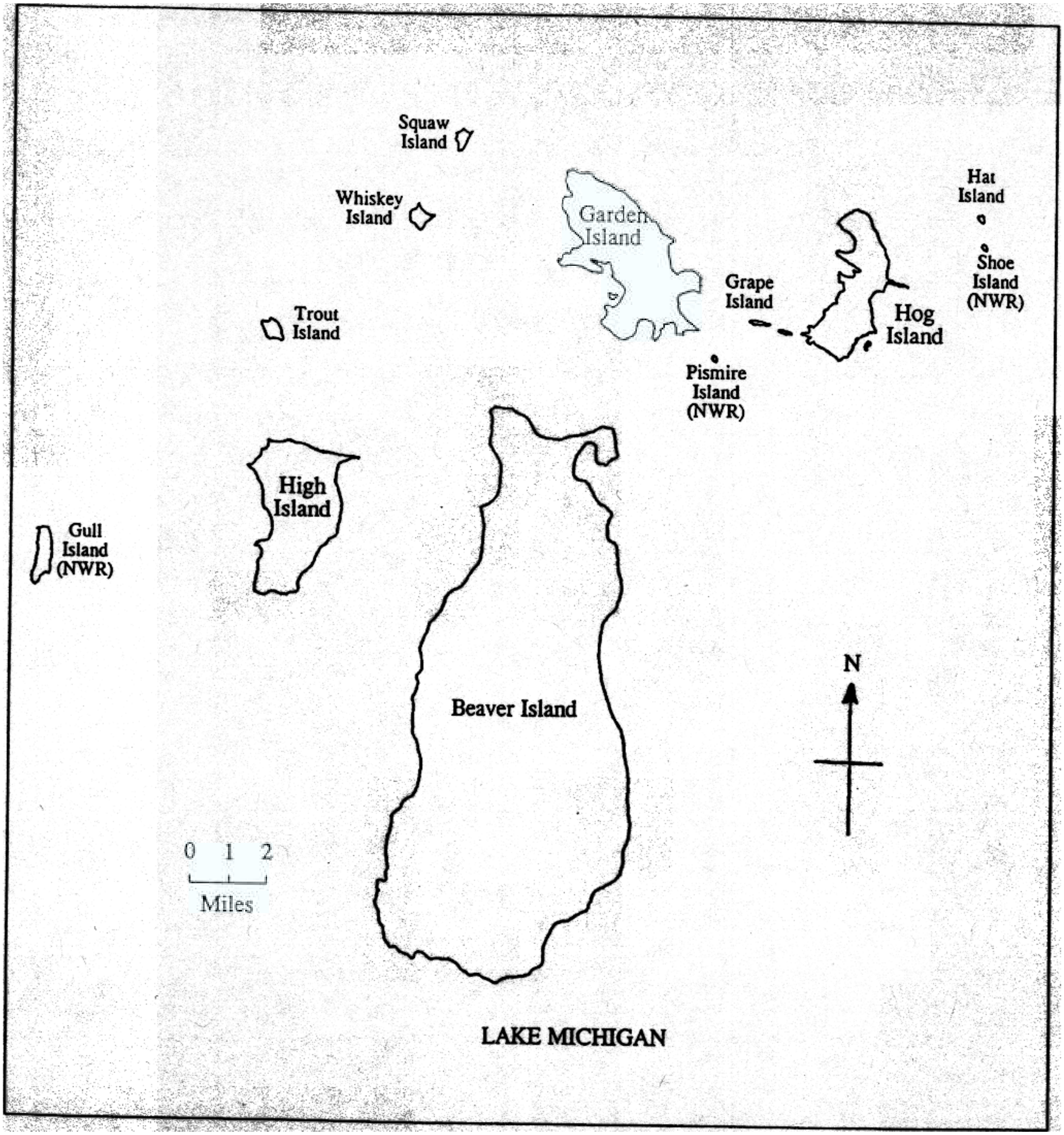

Figure 1. Location of Islands and Sampling Sites within the Beaver Islands, Lake Michigan, Michigan Islands NWR.

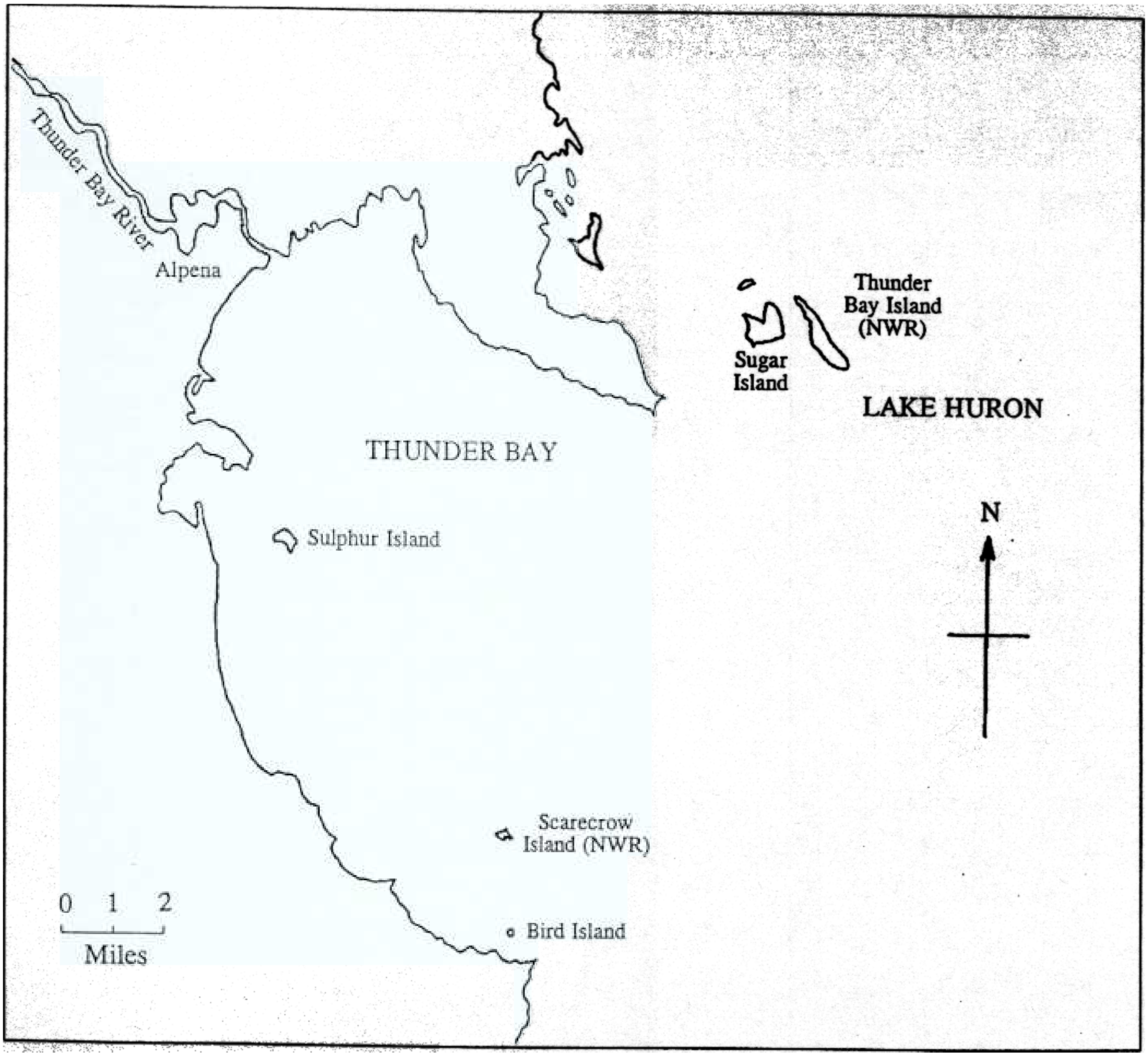

Figure 2. Location of Islands and Sampling Sites within Thunder Bay, Lake Huron, Michigan Islands, NWR

A conversion factor was calculated for each individual egg as a ratio of the mass of the actual egg contents to the mass of the maximum egg contents, as determined by water displacement. A mean of the individual conversion factors for the eggs from a breeding colony was used to represent the composite egg sample. This conversion factor was used to express egg contaminant residues on a fresh weight basis, *i.e.* at the time the eggs were laid.

Adult birds were lethally collected with firearms and steel shot. Juvenile birds were incidentally collected as fresh dead specimens fallen from nests. Thirteen birds were collected between June 22 and July 6, 1988 representing the mallard (*Anas platyrhynchos*), northern pintail (*A. acuta*), red-breasted merganser, double-crested cormorant and great blue heron. The birds were transported on ice to ELFO and frozen prior to processing. Each bird was weighed whole before removing skinless breast muscle and liver samples from the waterfowl, and liver samples from the colonial waterbirds. Each sample was weighed, placed in chemically clean jars and refrozen.

The biota samples were submitted for analysis of organochlorine pesticides (OC) including total PCBs (gas-liquid chromatography), aliphatic hydrocarbons (gas chromatography/mass spectrometry (GC/MS) with selective ion monitoring), mercury (Hg - cold vapor atomic absorption), and selenium (Se - graphite furnace atomic absorption) by analytical laboratories under contract to the PACF. Quality Assurance/Quality Control (QA/QC) of the contract laboratories was monitored by PACF through analysis of duplicate samples, matrix and reagent blanks, spiked samples, calibration checks, standard reference material samples, method blacks and GC/MS confirmation. Based on the QA/QC program, PACF determined that the results for the organic analyses (OCs and aliphatic hydrocarbons) and Se were acceptable. However, the results of the Hg analyses were deemed unacceptable. Based on these results, PACF reanalyzed 9 samples as a crosscheck. Based on these results, a correction factor (1.86) derived as the mean of the ratios of the results (PACF:contract laboratory) was calculated. This number was used by ELFO to correct those contract laboratory's results which were not reanalyzed by PACF. Therefore, the Hg results contained in this report should be considered approximations only.

Results and Discussion

Avian Tissues - Organics

Residues of OC compounds were detected in all samples but one liver sample (Tables 1 and 2). In individual samples, up to 9 OC compounds were detected in liver samples and 8 OCs in muscle samples, with the most detections occurring in the higher trophic level piscivorous waterfowl and colonial waterbirds. However, total PCBs, *p,p*'-DDE, oxychlordane, heptachlor epoxide, dieldrin and *t*-nonachlor were detected at levels elevated above detection limits. The other OCs (HCB, mirex, and other DDT metabolites) were detected at, or marginally above, detection limits. For those elevated OCs, the concentrations were highest in the piscivorous waterfowl and colonial waterbirds, indicative of foodchain biomagnification.

In individual birds, the concentration of the detected compounds in muscle and liver were similar to one another, as was noted in previous studies (Sarkka *et al.* 1978, Kim *et al.* 1984, 1985, Best *et al.* 1992, 1995). Owing to the low lipid content of both types of specimens (1.3-3.7% for muscle and 2.7-5.2% for liver), when total PCBs were detected, the lipid weight concentrations readily exceeded the USFDA Tolerance Level for poultry in interstate commerce (3.0 *ug*/g, lipid weight; 21 CFR 109.30). The removal of the skin and associated subcutaneous fat from the muscle samples, resulted in the low lipid values. Only four of 17 samples with detectable DDT compounds exceeded the Tolerance Level for DDT and metabolites (5.0 *ug*/g, lipid weight). Those samples exceeding the total DDT Tolerance Level were from piscivorous waterfowl. Colonial waterbirds showed even higher lipid weight concentrations of total DDT, but were not compared to the Tolerance Level due to the non-huntable status of these species.

All 13 individual aliphatic hydrocarbon compounds were detected in the liver and muscle samples. However, no one sample contained detectable quantities of all 13 compounds. Unlike the OCs, the concentrations of total aliphatics in liver samples were over twice the levels found in the muscle samples (Tables 1 and 2). This trend was also evident in the concentrations of the individual aliphatics between the two sample types. Except for the double crested cormorant, there was no evident pattern of foodchain biomagnification of total aliphatics in upper trophic level species.

As was demonstrated in 1985 within the south cell of the Saginaw Bay CDF (ELFO unpublished data), as little as ten days of exposure is required for gamefarm mallard hens to bioaccumulate total PCBs in exceedence of the Tolerance Level. Over the 86-day exposure period, the mean body burden for both PCBs and *p,p'*-DDE continued to increase and only total PCBs began to level off by day 86. This rapid bioaccumulation occurred in the presence of relatively low levels of PCBs in the sediments of the CDF. Only two of nine sediment samples had detectable PCBs (0.49 and 0.71 *ug*/g, wet weight).

Concurrent with the present study, ELFO was involved in the documentation of the biomagnification of H4IIE bioassay derived 2,3,7,8-tetrachlorodibenzo-*p*-dioxin equivalents (TCDD-EQ) within the foodchain of Thunder Bay (Jones *et al.* 1993), including the environs of Thunder Bay and Scarecrow Islands. Through the analysis of sediment and whole body burdens of resident fish and birds, the results indicated that the foodchain is the major pathway for biomagnification of TCDD-EQ, which incorporates the potencies of the dioxin-like PCBs. This biomagnification occurred at total PCB concentrations of 1.5 and 1.7 *ug*/g, wet weight for two composite sediment samples collected adjacent to the navigation channel off the mouth of the Thunder Bay River. Although no sediment samples in the near vicinity of the refuge islands were taken in the present study, such samples would not likely be as high as the Jones *et al.* (1993) samples, which were collected in a depositional area near the river mouth and potentially more influenced by point sources, spills and other incidents within the watershed (Appendix 1).

The levels of contamination in muscle and livers from the refuge islands are similar in magnitude to results of waterfowl samples collected by ELFO at Wyandotte NWR in the Detroit River (Best *et al.* 1992), a river system with a history of water quality problems including the presence of

OC compounds. Although sediment concentrations of total PCBs at Wyandotte NWR (1.0 and 1.1 *ug*/g, wet weight) are similar to or higher than what might be expected from the Michigan Islands environment, differences in species collected hamper comparisons of the two areas. No piscivorous waterfowl or colonial waterbirds were collected during the Wyandotte NWR study to compare biomagnification to similar trophic levels. For the mallard, a dabbling duck species collected during both studies, there was a trend toward higher total PCB concentrations in both tissue types at Wyandotte NWR. No trend was noted for total DDT.

Although the results from the refuge islands are similar to the Wyandotte NWR tissue results, they are considerably higher than tissues from waterfowl collected at Seney NWR (Best *et al.* 1995), which has no known history of point sources of pollution or water quality problems. No PCBs were detected in any waterfowl samples from Seney NWR. In Canada goose and dabbling duck samples, *p,p*'-DDE was detected in a few samples at the method detection limit. Only in the hooded merganser (*Lophodytes cucullatus)* samples were *p,p*'-DDE residues elevated above detection limits (0.01 *ug*/g, wet weight), but not to the levels found in the red-breasted merganser samples from the Michigan Islands NWR. Clearly, waterfowl and colonial waterbirds breeding within the Michigan Islands system are continuing to be exposed and bioaccumulating in body tissues OC compounds originating from historic inplace and/or ongoing sources.

Avian Tissues - Inorganics

The Hg results show greater accumulation in both tissue types from piscivorous waterfowl and colonial waterbirds than from dabbling ducks (Table 3). Residues of Hg typically were detected at levels well below those found in waterfowl from northwestern Ontario and Lake Paijanne in Finland (Vermeer and Armstrong 1972, Vermeer *et al.* 1973, Fimreite 1973, 1974, Sarkka *et al.* 1978) and in great blue herons from western Lake Erie (Hoffman and Curnow 1979). These areas have a history of water quality problems related, in part, to improper disposal of Hg from pulp and paper mills or chlor-alkali plants. However, the differences in Hg concentrations between the present study and these cited studies become reduced in liver samples from red-breasted mergansers. Compared to other areas with known or suspected Hg problems (Fimreite 1974, Best *et al.* 1992), the present study revealed similar levels of waterfowl exposure to Hg. Considerably lower concentrations of Hg were detected in muscle tissue than in livers for all adult birds (average of 24%), but not to the extent found in the Detroit River (37% lower, Best *et al.* 1992) or in the English-Wabigoon River system in northwestern Ontario (32% lower, Fimreite 1974).

While generally not as high as the above cited studies, Hg residues in waterfowl from the Michigan Islands were similar or slightly greater than the results derived from waterfowl surveys over broad geographical areas in Canada (Vermeer and Armstrong 1972, Pearce *et al.* 1976) where the most likely source of mercury would be via aerial deposition. Mercury residues were also lower from waterfowl sampled from Seney NWR (Best *et al.* 1995), where the likely inputs also would be from aerial deposition and/or parent bedrock/soils.

Mercury potentially may be a threat to the piscivorous birds breeding on the islands. All liver samples from these higher trophic level species exceed 2.0 *ug*/g Hg, fresh weight, the level associated with reproductive and behavioral deficiencies in domestic mallards (as reviewed in Eisler 1987). However, the toxicological meaning of this data set is complicated by the estimated nature of the Hg results. This aspect needs further study to better quantify Hg exposure and affects.

There are currently no State or Federal guidelines regarding Hg in edible portions of avian or mammalian wildlife for human consumption. However, if one were to consider the edible portion of a fish as an analogous situation, some of the waterfowl samples, particularly for the piscivorous species, would exceed the State of Michigan level of public concern (0.5 *ug*/g, wet weight) and/or the US Food and Drug Administration tolerance level (1.0 *ug*/g, wet weight) for Hg in fish.

The results reveal surprisingly high Se bioaccumulation in waterfowl and colonial waterbird tissues (Table 3). Little Se was detected in the breast muscle samples when compared to the liver samples. There was no indication of higher Se concentrations in tissues from the piscivorous species, as was seen for OCs and Hg.

The levels of Se in the liver tissues suggest above normal exposure to Se and the potential for reproductive impairment via embryo toxicity, terata and poor chick survival, and adult toxicosis via severe emaciation, breast muscle atrophy, degenerative liver changes and abnormal feather loss (Ohlendorf 1989). Normal background concentrations of Se in avian livers from freshwater habitats average 4-10 *ug*/g, dry weight (as summarized by Ohlendorf 1989). Over half of the liver samples from the present study exceed this background range of values. In agricultural drainage water studies in California, where waterfowl and waterbirds have been highly exposed and impacted by Se, mean levels of Se in livers ranged from 11.2-15.6 *ug*/g, dry weight for three species in the Imperial Valley, and 19.9-127 *ug*/g, dry weight for four species from the Kesterson NWR (as summarized by Ohlendorf 1989). The Kesterson study also found that liver concentrations of Se nearly doubled over the course of the breeding season as onsite exposure continued. At control sites, mean liver residues ranged from 2.8-8.8 *ug*/g, dry weight. Clearly, these data place Michigan Islands NWR birds at risk from Se exposure.

Avian Eggs - Organics

The results indicate that the Michigan Islands birds continue to be exposed to a similar suite of OCs as found in fresh and addled eggs of other Great Lakes avian species (Table 4). Not unexpectedly, the levels of PCBs in some of the samples rival those found in recent fresh and addled eggs of colonial fish-eating cormorants and terns in the Great Lakes (Kubiak *et al.* 1989, Weseloh *et al.* 1989, Smith *et al.* 1990, Tillitt *et al.* 1991, Yamashita *et al.* 1993, Jones *et al.* 1994). The results also indicate that the OCs residues have been considerably reduced from earlier waterfowl samples (1977-78) collected from Lake Michigan off Door County, Wisconsin, particularly for the red-breasted merganser (Haseltine *et al.* 1981). For the common tern, total PCB residues in the Michigan Islands' eggs are currently less than half the residues in common and Forster's tern (*Sterna forsteri*) eggs collected by ELFO in 1988 from the Detroit River, Lake St. Clair and Saginaw Bay and River (Best *et al.* 1992), areas with long-standing problems of inplace pollutants. Other OC residues were more comparable, except for dieldrin and total aliphatics which were twice the values from these other recently sampled sites.

Exposure to this complex mixture of Great Lakes contaminants, particularly PCBs and other dioxin-like compounds, has been strongly implicated in the occurrence of terata in avian embryos and nestlings, as well as other wildlife (Hoffman *et al.* 1987, Bishop *et al.* 1991, Fox *et al.* 1991, Gilbertson *et al.* 1991, Heaton 1992, Summer 1992, Yamashita *et al.* 1993, Bowerman *et al.* 1994, Giesy *et al.* 1994). The suite of hard and soft-tissue deformities exhibited by Great Lakes birds is one aspect of an overall reproductive impairment syndrome referred to as the Great Lakes Embryo Mortality, Edema and Deformities Syndrome (GLEMEDS - Gilbertson *et al.* 1991). Avian deformities were noted in the present study. Of the seven red-breasted merganser eggs collected at the pipping stage from Pismire Island, all 5 of the eggs that contained embryos exhibited incomplete yolk sac adsorption, a condition known as gastroschisis. In addition, one great blue heron nestling recovered from Scarecrow Island was cross-billed. The liver from this specimen contained 6.3 *ug*/g, wet weight of total PCBs (Table 2). Subsequent to this study, several double-crested cormorant nestlings on Scarecrow Island in 1993 were also noted with cross-bills (D. Spencer pers. comm.). All of these deformities are consistent with GLEMEDS.

PCB concentrations in the range detected in the present study may be expected to result in reproductive failure. The lowest observable adverse effect level for total PCBs in studies of avian reproduction (chickens) is 0.87 *ug*/g, fresh weight (Britton and Huston 1973) while PCBs in the range of 5-15 *ug*/g, fresh weight, clearly impairs the hatchability of chicken eggs (as reviewed in Kubiak *et al.* 1989). In a native Great Lakes species, reproductive success in Forster's terns in Green Bay was impaired at median egg concentrations of 22.2 *ug*/g, fresh weight, of total PCBs, when other contaminants were present (Kubiak *et al.* 1989). Not only were PCBs an intrinsic factor to the poor egg hatchability, but they also contributed to the overall reproductive impairment through extrinsic factors (parental inattentiveness). Similar extrinsic effects have been noted in Great Lakes herring gulls (Peakall and Fox 1987). In 1987, a 12-egg composite of double-crested cormorant eggs, from Gull Island, Michigan Islands NWR, contained 6.7 *ug*/g, PCBs wet weight (Jones *et al.* 1994), similar to the results from the present study (5.5 *ug*/g). This residue level was associated with 27% egg lethality at day 23 of incubation in the colony in 1987. For the bald eagle (*Haliaeetus leucocephalus*), the highest trophic level avian species likely to be encountered in the Michigan Islands NWR, it has been estimated that total PCB egg residues in excess of 4.0-6.0 *ug*/g, fresh weight would begin to impair reproduction (Wiemeyer 1990, Kubiak and Best 1991).

The detected levels of *p,p*'-DDE in the eggs from the refuge are also of concern to the reproductive health of birds, and are similar to waterfowl and colonial waterbird eggs from other sites within the Great Lakes (Niemi *et al.* 1986, Kubiak *et al.* 1989, Weseloh *et al.* 1989, Ewins *et al.* 1992, Yamashita *et al.* 1993). At a common tern colony in Alberta, mean DDE levels of 3.42 *ug*/g, fresh weight, in eggs resulted in abnormalities in shell structure and composition which led to embryo death and reproductive impairment (Fox 1976). For the bald eagle, *p,p'*-DDE egg residues in excess of 1.0-1.7 *ug*/g, fresh weight is anticipated to impair reproduction (Wiemeyer *et al.* 1984, Kubiak and Best 1991).

Avian Eggs - Inorganics

Selenium residues in the eggs (Table 5) may also be a problem, as reproductive impairment in wild birds may occur at egg residues as low as 1.0 *ug*/g, fresh weight (Heinz *et al.* 1989). Individual and composite results exceed this value for several species. In addition, individual eggs within composites with results < 1.0 *ug*/g, fresh weight, may also exceed this threshold value. However, toxicity varies with the different chemical forms of Se which were not determined for these eggs.

In the Kesterson NWR studies, Se residues in eggs of various shorebirds and waterfowl were in the range of 2.2-110 *ug*/g, dry weight, with lower values reported for species whose food habits are more dominated by plant matter, rather than by fish or aquatic insects (Ohlendorf *et al.* 1986). Selenium toxicity resulted in poor hatchability (embryotoxicity) and greatly elevated rates of hard and soft-tissue deformities in hatchlings, similar to GLEMEDS. From these studies, a reference value of 1.0-3.0 *ug*/g of Se, dry weight was considered indicative of normal Se egg residues in wild birds from non-Se enriched environments (Ohlendorf *et al.* 1986, Skorupa and Ohlendorf 1991). Greater than 3 *ug*/g Se, dry weight in eggs was considered a reasonable indicator for avian contamination in nonmarine environments (Skorupa and Ohlendorf 1991). Skorupa and Ohlendorf (1991) also established avian thresholds for embryotoxicity for both individual and mean egg Se concentrations. Hatchability was considered a more sensitive indicator than teratogenicity, with a threshold of 8.0 *ug*/g, dry weight for mean egg Se and 10.0 *ug*/g, dry weight for individual egg Se. A threshold range of 13-24 *ug*/g, dry weight for mean egg Se was associated with teratogenic populations of aquatic birds. Data from the present study indicates that the Michigan Islands NWR breeding birds are exposed to a Se enriched environment at levels which may be impairing reproduction.

Mercury residues in the eggs (Table 5) do not appear to be a problem in of themselves, since they are all below the range of 0.79-2.0 *ug*/g, fresh weight associated with impaired reproduction in various bird species (as reviewed in Eisler 1987). Egg residues at the low end of this range were associated with impaired reproduction and altered behaviors in young mallards, in a multi-generational feeding study (Heinz 1979). In a Finnish study of ospreys (*Pandion haliaetus*), addled egg residues of 0.1-0.4 *ug*/g, fresh weight of Hg were considered not to be the cause of the eggs' failure to hatch (Hakkinen and Hasanen 1980). Residues of Hg in addled bald eagle eggs from Michigan and Ohio in 1986-89, from both inland and Great Lakes sites, fall within a similar range (0.06-0.31 *ug*/g fresh weight) and are also not considered to affect hatchability (ELFO unpublished data). Surprisingly, Hg residues in the individual red-breasted merganser eggs were only marginally lower than that reported 10 years earlier from northern Lake Michigan (Haseltine *et al.* 1981). It must be remembered that individual eggs within our analyzed egg composites will be higher than the composite results reported in Table 5, and may approach or exceed a general avian or species specific threshold for the manifestation of effects. In addition, Hg interacts antagonistically with Se (Peereboom-Stegeman 1987, Eisler 1987) and synergistically with PCBs (Wren *et al.* 1987) in the expression of effects. To our knowledge, Hg has not been previously identified as a problem pollutant to wildlife in the open waters of the Great Lakes.

Exposure Summary

Clearly, the egg residues confirm the continued exposure of Service trust resources to a suite of organic and inorganic contaminants within the Great Lakes ecosystem. The levels of these residues also suggest continued reproductive impairment in theses species, as well as others not assessed in the present study. Whether impacts to trust resources are occurring and to what extent, if any, egg residues and body burdens of these contaminants decline over time is a subject which should be addressed through continued monitoring. Such a monitoring effort should be expanded to all Service islands and coastal lands within the Great Lakes, perhaps to be eventually incorporated into the Biomonitoring of Environmental Status and Trends Program being developed by the National Biological Service. Such a survey effort would entail several visits to all sites to make egg collections, sample appropriate tissues from adults and juveniles, assess rates of deformities in hatchlings and addled eggs, and determine productivities of selected species.

Recommendations

Reproduction of colonial waterbirds and waterfowl within the Great Lakes has been long impacted by industrial and agricultural sources of contaminants within the basin. The results of this survey suggests that body burdens of several organic compounds and selenium are still sufficiently elevated to continue to affect reproduction in many species. This reproductive impairment is corroborated by the existence of hard and soft-tissue deformities, consistent with the GLEMEDS. While this survey did not address possible sources of these elevated contaminants, it is highly unlikely that there are any onsite point sources on any of the islands. Probable sources are inplace pollutants within the lower trophic levels of the Great Lakes food web. Aerial deposition of contaminants may contribute to current historical inplace loadings to the Great Lakes system. No site specific remedial actions are recommended.

Based on the above data and discussions, we offer the following recommendation for Service consideration:

1. Due to the elevation of organic and inorganic contaminants in several avian species, the Service should continue to monitor on a periodic basis the contaminant body burdens and residues in egg composites from birds breeding on the islands. The survey should also include an assessment of the reproductive outcomes of the breeding species, and full documentation of deformities. In the short term, this should be accomplished as an effort between the ELFO's Environmental Contaminants Program and the Seney and Shiawassee NWRs.

Similar efforts are recommended for other refuge property with the Great Lakes, including Huron Islands, Harbor Island and Wyandotte NWRs in Michigan. Over the long term, an expanded assessment of avian reproduction and contaminant exposure may be incorporated into the Biomonitoring of Environmental Status and Trends Program being developed by the National Biological Service.

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Table 1. Wet Weight and Lipid Weight Concentrations of Organic Compounds (*ug*/g) in Skinless Breast Muscles from Waterfowl, Michigan Islands NWR.

		Total PCBs		Total DDT		Total Aliphatics[1]
		Wet Weight	Lipid Weight	Wet Weight	Lipid Weight	Wet Weight
Red-Breasted Merganser						
Thunder Bay Isd.	Ad.♂	2.4	91.6[2]	0.90	34.4[3]	0.36
Pismire Isd.	Ad.♀	1.8	75.3[2]	0.49	20.5[3]	0.38
Mallard						
Gull Isd.	Ad.♀	0.26	9.7[2]	0.05	1.9	0.47
Grape Isd.	Ad.♀	ND[4]	ND[5]	0.02	0.68	0.31
Grape Isd.	Ad.♂	ND[4]	ND[5]	0.02	0.54	0.45
Grape Isd.	Ad.♂	ND[4]	ND[5]	0.03	1.00	0.66
Grape Isd.	Ad.♂	ND[4]	ND[5]	0.03	1.06	0.98
Thunder Bay Isd.	juv.	ND[4]	ND[5]	0.05	3.9	0.72
Northern Pintail						
Thunder Bay Isd.	Ad.♀	0.35	15.2[2]	0.08	3.5	0.87

Summation of 13 Aliphatic Hydrocarbon compounds.
Exceeds USFDA Tolerance Level for Total PCBs in poultry for interstate commerce, >3.0 *ug*/g, lipid weight.
Exceeds USFDA Tolerance Level for Total DDT in poultry for interstate commerce, >5.0 *ug*/g, lipid weight.
Total PCBs not detected, <0.05 *ug*/g, wet weight.
Total PCBs not detected, <2.39 *ug*/g (mean), lipid weight.

Table 2. Wet Weight and Lipid Weight Concentrations of Organic Compounds (ug/g) in Livers from Waterfowl and Colonial Waterbirds, Michigan Islands NWR.

		Total PCBs		Total DDT		Total Aliphatics[1]
		Wet Weight	Lipid Weight	Wet Weight	Lipid Weight	Wet Weight
Red-Breasted Merganser						
Thunder Bay Isd.	Ad.♂	5.1	144.9[2]	0.97	27.6[3]	1.1
Pismire Isd.	Ad.♀	2.0	60.4[2]	0.60	18.1[3]	2.4
Mallard						
Gull Isd.	Ad.♀	ND[4]	ND[5]	0.06	1.8	1.4
Grape Isd.	Ad.♀	ND[4]	ND[5]	0.04	1.2	0.84
Grape Isd.	Ad.♂	ND[4]	ND[5]	ND[6]	ND[7]	1.7
Grape Isd.	Ad.♂	ND[4]	ND[5]	0.03	0.57	1.7
Grape Isd.	Ad.♂	ND[4]	ND[5]	0.05	1.1	1.6
Thunder Bay Isd.	juv.	ND[4]	ND[5]	0.07	2.4	1.2
Northern Pintail						
Thunder Bay Isd.	Ad.♀	ND[4]	ND[5]	0.10	2.8	1.8
Double-Crested Cormorant						
Scarecrow Isd.	Ad.	11.0	217.8	2.2	42.6	14.6
Great Blue Heron						
Scarecrow Isd.	juv.[8]	6.3	230.8	3.6	133.3	0.87

Table 2. continued.

Summation of 13 Aliphatic Hydrocarbon compounds.
Exceeds USFDA Tolerance Level for Total PCBs in poultry for interstate commerce, >3.0 *u*g/g, lipid weight.
Exceeds USFDA Tolerance Level for Total DDT in poultry for interstate commerce, >5.0 *u*g/g, lipid weight.
Total PCBs not detected, <0.05 *u*g/g, wet weight.
Total PCBs not detected, <2.39 *u*g/g (mean), lipid weight.
Total DDT not detected, <0.01 *u*g/g, wet weight.
Total DDT not detected, <0.50 *u*g/g (mean), lipid weight.
Fresh dead chick with cross-bill.

Table 3. Wet and Dry Weight Concentrations of Heavy Metals (ug/g) in Livers and Skinless Breast Muscles from Waterfowl and Colonial Waterbirds, Michigan Islands NWR.

		Liver				Muscle	
		Hg		Se		Hg	Se
		wet wt	dry wt	wet wt	dry wt	wet wt	wet wt
Red-Breasted Merganser							
Thunder Bay Isd.	Ad.♂	14.2[1]	51.0[2]	7.9	28.5	0.95	1.4
Pismire Isd.	Ad.♀	6.4	22.9	7.9	28.1	0.99	1.1
Mallard							
Gull Isd.	Ad.♀	0.28	1.0	7.2	26.0	ND[3]	1.2
Grape Isd.	Ad.♀	0.27	1.0	2.3	8.6	ND[3]	0.91
Grape Isd.	Ad.♂	0.15[1]	0.53[2]	1.2	4.2	0.10	0.72
Grape Isd.	Ad.♂	0.34	1.2	3.2	11.2	0.06[1]	0.82
Grape Isd.	Ad.♂	0.91	3.3	2.5	9.3	0.23	0.65
Thunder Bay Isd.	juv.	0.12	0.52	7.1	30.4	0.08	1.4
Northern Pintail							
Thunder Bay Isd.	Ad.♀	0.41	1.4	10.3	35.9	0.08[1]	2.0
Double-Crested Cormorant							
Scarecrow Isd.	Ad.	2.9	9.7	12.6	42.6		
Great Blue Heron							
Scarecrow Isd.	juv.[4]	3.6[1]	14.0[2]	2.1	8.1		

Table 3. continued.

Wet weight conversion of actual dry weight result from PACF.

[2] Actual dry weight result from PACF; others are dry weight estimates using correction factor (1.86) derived from the mean of the ratios of the dry weight results (PACF:contract laboratory).

[3] Hg not detected, <0.05 ug/g, wet weight.

Fresh dead chick with cross-bill.

Table 4. Fresh Weight Concentrations of Organic Compounds (*ug*/g) in Colonial Waterbird Egg Composites and Waterfowl Eggs, Michigan Islands NWR.

	# Eggs	Total PCBs	*p,p'*-DDE	Total DDT	Dieldrin	Oxychlor-dane	Hept. Epox.
Double-Crested Cormorant							
Grape Isd.	12	6.3[2]	6.9	7.0	0.21	0.09	0.12
Gull Isd.	12	5.5[2]	6.5	6.5	0.23	0.09	0.08
Scarecrow Isd.	9	6.4[2]	4.5	4.5	0.13	0.05	0.06
Herring Gull							
Gull Isd.	12	19.3[2]	11.1	11.2	0.65	0.58	0.56
Pismire Isd.	10	12.9[2]	7.7	7.8	0.56	0.37	0.41
Thunder Bay Isd.	11	7.8[2]	3.5	3.6	0.22	0.15	0.15
Ring-Billed Gull							
Thunder Bay Isd.	11	2.5[2]	1.2	1.3	0.49	0.06	0.11
Common Tern							
Thunder Bay Isd.	11	3.5[2]	1.1	1.1	0.20	0.04	0.05
Great Blue Heron							
Scarecrow Isd.	10	2.6[2]	4.2	4.2	0.19	0.14	0.12
Black-Crowned Night Heron							
Scarecrow Isd.	3	8.9[2]	3.3	3.3	0.09	0.12	0.13
Red-Breasted Merganser							
Pismire Isd.[4]	1[5]	2.9[2]	2.2	2.2	0.49	0.13	0.18
	1	3.0[2]	2.0	2.2	0.37	0.14	0.15
	1[5]	2.7[2]	2.0	2.1	0.44	0.16	0.18
	1	2.9[2]	1.8	1.9	0.30	0.12	0.13
	1[5]	3.4[2]	2.3	2.5	0.52	0.07	0.19
	1[5]	3.1[2]	2.3	2.4	0.49	0.14	0.18
	1[5]	3.2[2]	2.7	2.9	0.57	0.18	0.20
Canada Goose							
Pismire Isd.	1	0.16	0.05	0.05	0.01	0.01	0.01

Table 4. continued.

	# Eggs	HCB	trans-Nonachlor	alpha-Chlordane	cis-Nonachlor	Mirex	Total Aliphatics[1]
Double-Crested Cormorant							
Grape Isd.	12	0.01	0.05	0.02	0.07	0.05	0.26
Gull Isd.	12	0.01	0.01	ND[3]	0.05	0.05	0.19
Scarecrow Isd.	9	0.01	0.01	ND[3]	0.27	0.04	0.20
Herring Gull							
Gull Isd.	12	0.06	0.25	0.04	0.18	0.08	0.85
Pismire Isd.	10	0.05	0.17	0.03	0.14	0.08	0.49
Thunder Bay Isd.	11	0.03	0.10	0.02	0.08	0.05	0.58
Ring-Billed Gull							
Thunder Bay Isd.	11	0.01	0.16	0.04	0.05	0.01	0.71
Common Tern							
Thunder Bay Isd.	11	0.02	0.07	0.02	ND[3]	0.01	1.63
Great Blue Heron							
Scarecrow Isd.	10	0.01	0.36	0.05	0.09	0.06	0.53
Black-Crowned Night Heron							
Scarecrow Isd.	3	0.01	0.12	0.01	ND[3]	0.12	0.39
Red-Breasted Merganser							
Pismire Isd.[4]	1[5]	0.02	0.18	0.03	0.08	0.02	0.56
	1	0.02	0.14	0.03	ND[3]	0.01	0.53
	1[5]	0.03	0.16	0.03	0.09	0.02	0.58
	1	0.02	0.13	0.03	0.07	0.02	0.48
	1[5]	0.01	0.19	0.02	0.10	0.02	0.35
	1[5]	0.02	0.20	0.04	0.10	0.02	0.55
	1[5]	0.02	0.20	0.03	0.11	0.02	0.57
Canada Goose							
Pismire Isd.	1	ND[3]	0.01	ND[3]	ND[3]	ND[3]	0.22

Table 4. continued.

Summation of 13 Aliphatic Hydrocarbon compounds.
Exceeds USFDA Tolerance Level for Total PCBs in eggs for interstate commerce, >0.3 *u*g/g, wet weight.
Not detected, <0.01 *u*g/g, fresh weight.
Red-Breasted Merganser eggs were collected from the same clutch and analyzed individually.
Embryo exhibiting gastroschisis - incomplete yolk sac adsorption at time of pipping.

Table 5. Fresh and Dry Weight Concentrations of Heavy Metals (*ug*/g) in Colonial Waterbird Egg Composites and Waterfowl Eggs, Michigan Islands NWR.

	# Eggs	Hg		Se	
		fresh wt	dry wt	fresh wt	dry wt
Double-Crested Cormorant					
Grape Isd.	12	0.17[1]	1.1[2]	0.60	4.0
Gull Isd.	12	0.26	1.9	0.54	3.8
Scarecrow Isd.	9	0.34	2.4	0.60	4.2
Herring Gull					
Gull Isd.	12	0.20[1]	0.89[2]	0.80	3.5
Pismire Isd.	10	0.30	1.4	0.88	4.0
Thunder Bay Isd.	11	0.18	0.82	1.2	5.5
Ring-Billed Gull					
Thunder Bay Isd.	11	0.20	0.89	0.90	4.1
Common Tern					
Thunder Bay Isd.	11	0.21	1.1	0.81	4.3
Great Blue Heron					
Scarecrow Isd.	10	0.33	2.0	0.45	2.8
Black-Crowned Night Heron					
Scarecrow Isd.	3	0.17	1.0	0.71	4.3
Red-Breasted Merganser					
Pismire Isd.[3]	1[4]	0.32	1.1	1.0	3.7
	1	0.39	1.3	0.97	3.2
	1[4]	0.44	1.6	0.98	3.6
	1	0.64[1]	2.2[2]	0.78	2.7
	1[4]	0.35	1.3	0.85	3.2
	1[4]	0.35	1.3	0.74	2.6
	1[4]	0.37	1.4	1.2	4.4
Canada Goose					
Pismire Isd.	1	<0.02[1]	<0.05[2]	<0.10	<0.33

Table 5. continued.

[1] Wet weight conversion of actual dry weight result from PACF.
[2] Actual dry weight result from PACF; others are dry weight estimates using correction factor (1.86) derived from the mean of the ratios of the dry weight results (PACF:contract laboratory).
[3] Red-Breasted Merganser eggs were collected from the same clutch and analyzed individually.
[4] Embryo exhibiting gastroschisis - incomplete yolk sac adsorption at time of pipping.